The Realization of Inflatable Array Antenna

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JPL/NASA's deep-space exploration and Earth remote sensing programs have been placing emphasis on reducing the mass and stowage volume of their spacecraft's high-gain and large aperture antennas. To achieve these goals, the concept of inflatable planar array antenna has recently been introduced at JPL. Because the planar array's flat aperture is a "natural" surface, its required surface tolerance is much easier to be maintained by the inflatable structure than that for a specifically curved surface such as a parabola. In addition, a planar array offers the possibility of wide-angle electronic beam scanning. Certainly, to realize this inflatable array antenna technology, several technical challenges remain to be resolved. In the RF area, it is essential to mitigate the array's weaknesses of narrow bandwidth and poor efficiency. In the mechanical area, the development of the inflatable structure rigidization technique, controlled deployment technique, and the structure dynamic analysis technique are inevitable.

Two inflatable array antennas that were developed recently are a 3.3m x 1.0m L-band synthetic aperture radar (SAR) array for Earth remote sensing application and a 1.0m diameter X-band reflectarray for deep-space telecom application. The L-band SAR array is a 1/3 size technology demonstration model of the future full-size (10m x 3m) array. It consists of a rectangular frame with an inflatable tube that supports and tensions a three-layer thin-membrane radiating surface with microstrip patches, ground plane, and microstrip power division lines. The measured results show that the antenna has achieved the required bandwidth of 80 MHz at the center frequency of 1.25 GHz and a peak gain of 25.2 dB with an aperture efficiency of 52%. The antenna has a total mass of 15 Kg with an average of 4.3 Kg/m^2, which includes the inflation system and its container. It is projected that the full-size array would achieve an average mass of 2 Kg/m^2. The membrane surface achieved the required global flatness of less than $\pm$ 1cm and local flatness of $\pm$ 0.75 mm. The second inflatable array antenna is an X-band reflectarray, which has an inflated torus tube that supports and tensions a 1.0m diameter two-layer-membrane reflectarray surface. The top layer has many isolated microstrip patches and is separated 1.3 mm from the bottom ground plane layer. A set of inflated tripod tubes is attached to the torus as struts to support the feed horn. The same tube and thin-membrane materials are used here as that described above for the SAR array. This inflatable antenna structure achieved a mass of 1.2 Kg (excluding the inflation system). The antenna achieved good radiation pattern with both peak sidelobe and peak cross-pol levels below -18 dB. The overall antenna efficiency was measured to be 37%, which could be improved in the future to become higher than 50%. The performances of both above antennas have proven that the inflatable array antenna technology is now realizable.

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The Realization of Inflatable Array Antennas

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Functional requirement:

- **Communications**
- **Remote sensing**

Antenna requirement:

- **High gain and large aperture**
- **Low mass**
- **Small launch-vehicle stowage volume**
- **Low cost**

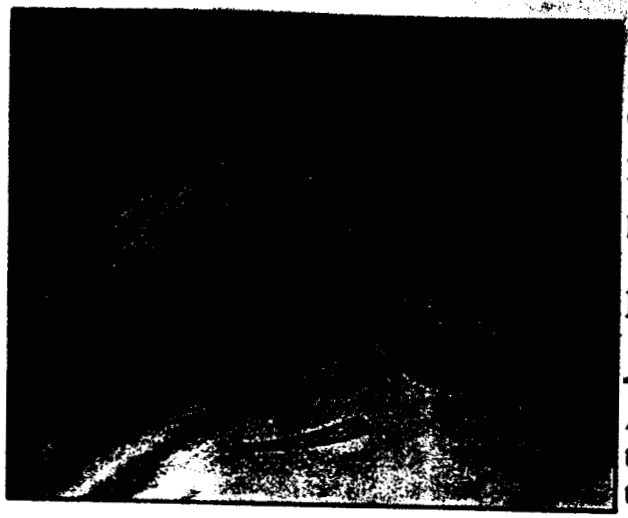
First Solution: Inflatable parabolic reflector

Program: NASA's IN-STEP Program
Inflatable Antenna Experiment (IAE)

A 14m dia. Inflatable parabolic reflector was flown on the space shuttle Endeavor in May 1996.

Successful deployment but poor surface tolerance

INFLATABLE ANTENNA EXPERIMENT



The on-orbit inflation and operation of the Inflatable Antenna Experiment (IAE) on Monday, May 20, 1996, was fantastic! The first views from Endeavour were visually stunning, and the experiment team is anticipating the arrival of the data stored onboard the Spartan 207 spacecraft upon it's arrival back on Earth. The entire Spartan 207/IAE/STS-77 Space Team at L'Garde, JPL, GSFC, JSC, KSC are to be congratulated for their dedication, great skill, and hard work.

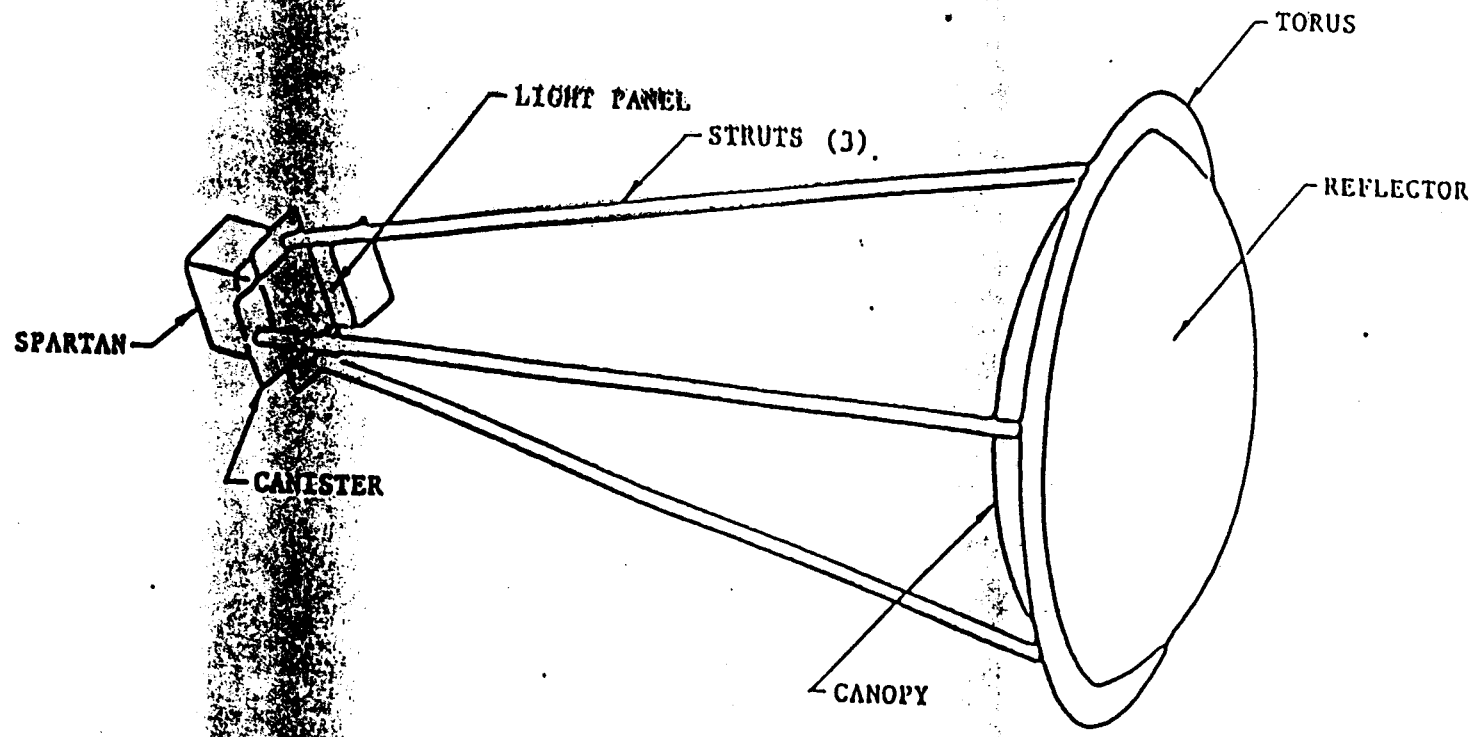
Mission Photos & Videos

A large antenna that inflates like a balloon, a technology validation experiment meant to lay the groundwork for future inflatable space structures such as large satellite antennas and telescopes, will be carried into space by the space shuttle Endeavor and released into Earth orbit.

The STS-77 mission in mid-May 1996 will deploy and test the Inflatable Antenna Experiment (IAE), developed by L'Garde, Inc. of Tustin, CA and NASA's Jet Propulsion Laboratory (JPL) of Pasadena, CA. The IAE will be flown as the sole experiment on the Goddard Space Flight Center's Spartan 207 mission.

- **Mission Purpose**
- **How the Antenna Is Stored**
- **How the Antenna Is Deployed - Quick-Time Video of Simulated**

INFLATABLE ANTENNA EXPERIMENT



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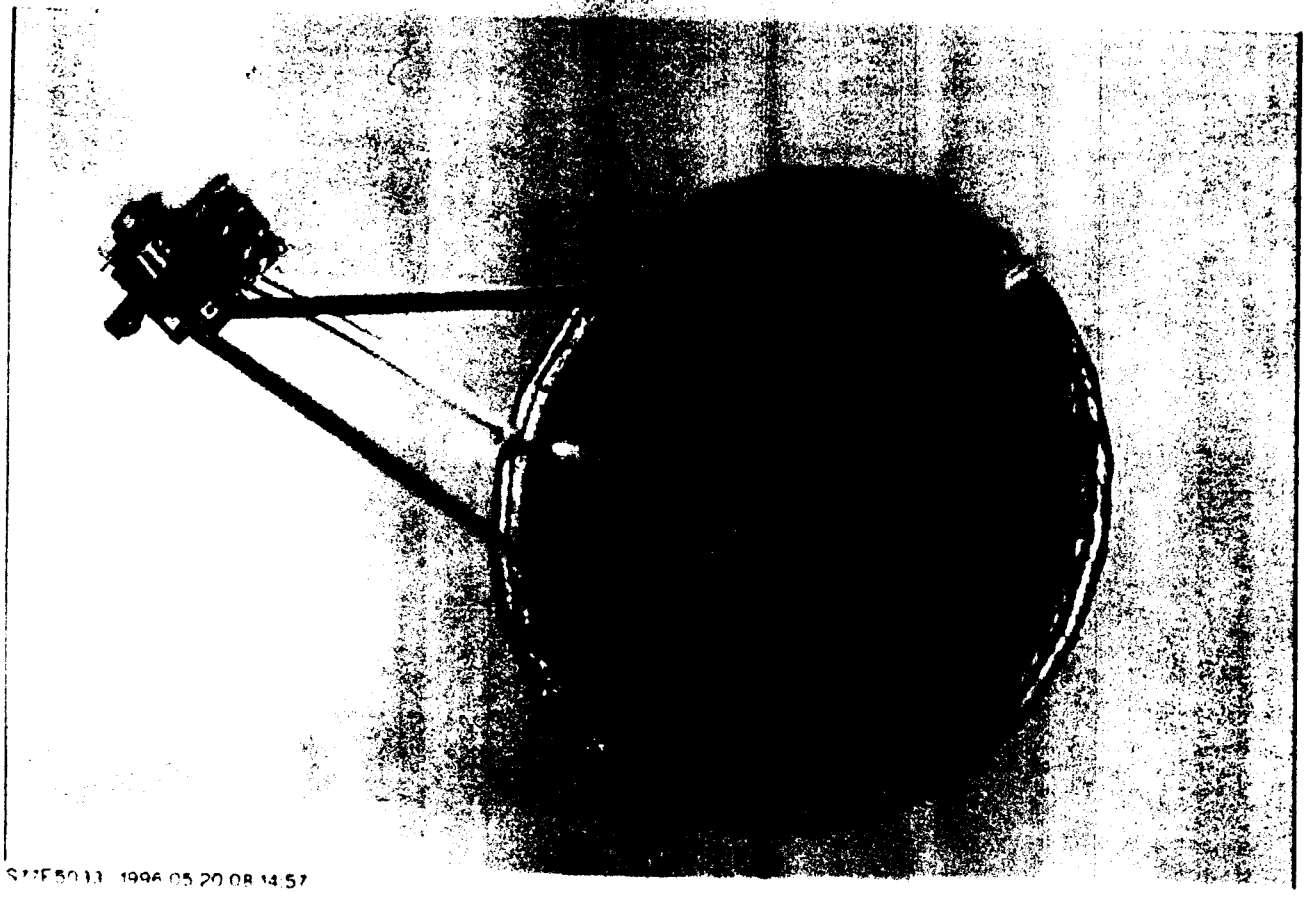


S77E5033 1996 05 20 08 14 57

Alternative solution: Inflatable thin-membrane flat array antennas

Reasons:
1. Much easier and more reliable to maintain a flat "nature" surface than a curved parabola
2. Possible to achieve wide beam scanning

Disadvantage: Small bandwidth

The Realization of Inflatable Array Antenna

Currently two types of flat inflatable array:

1. Inflatable phased array

   - 3.3m x 1.0m L-band dual-pol microstrip array

2. Inflatable reflectarray

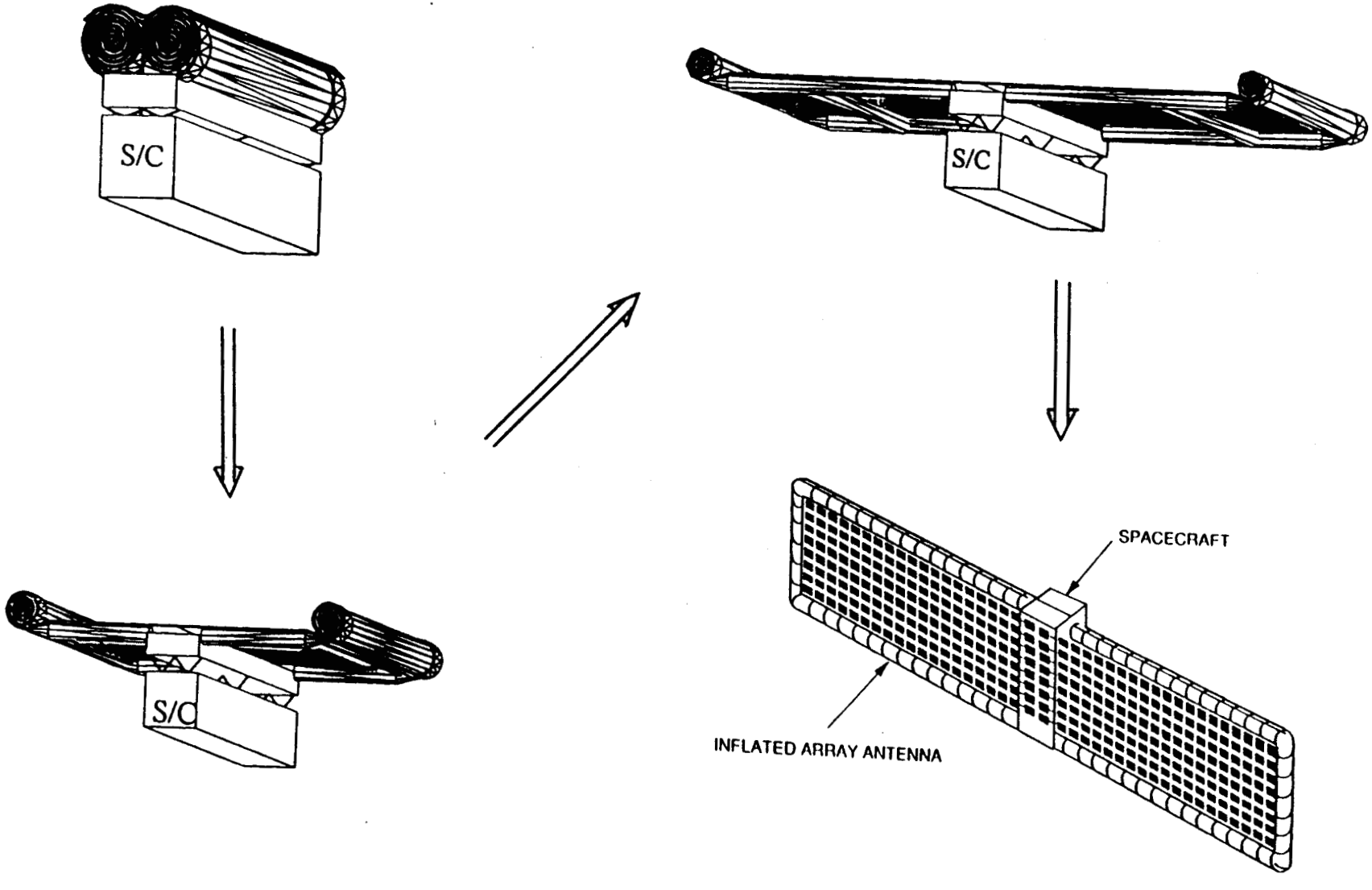
   - 1.0m dia. X-band CP microstrip reflectarray
   - 3.0m dia. Ka-band CP microstrip reflectarray

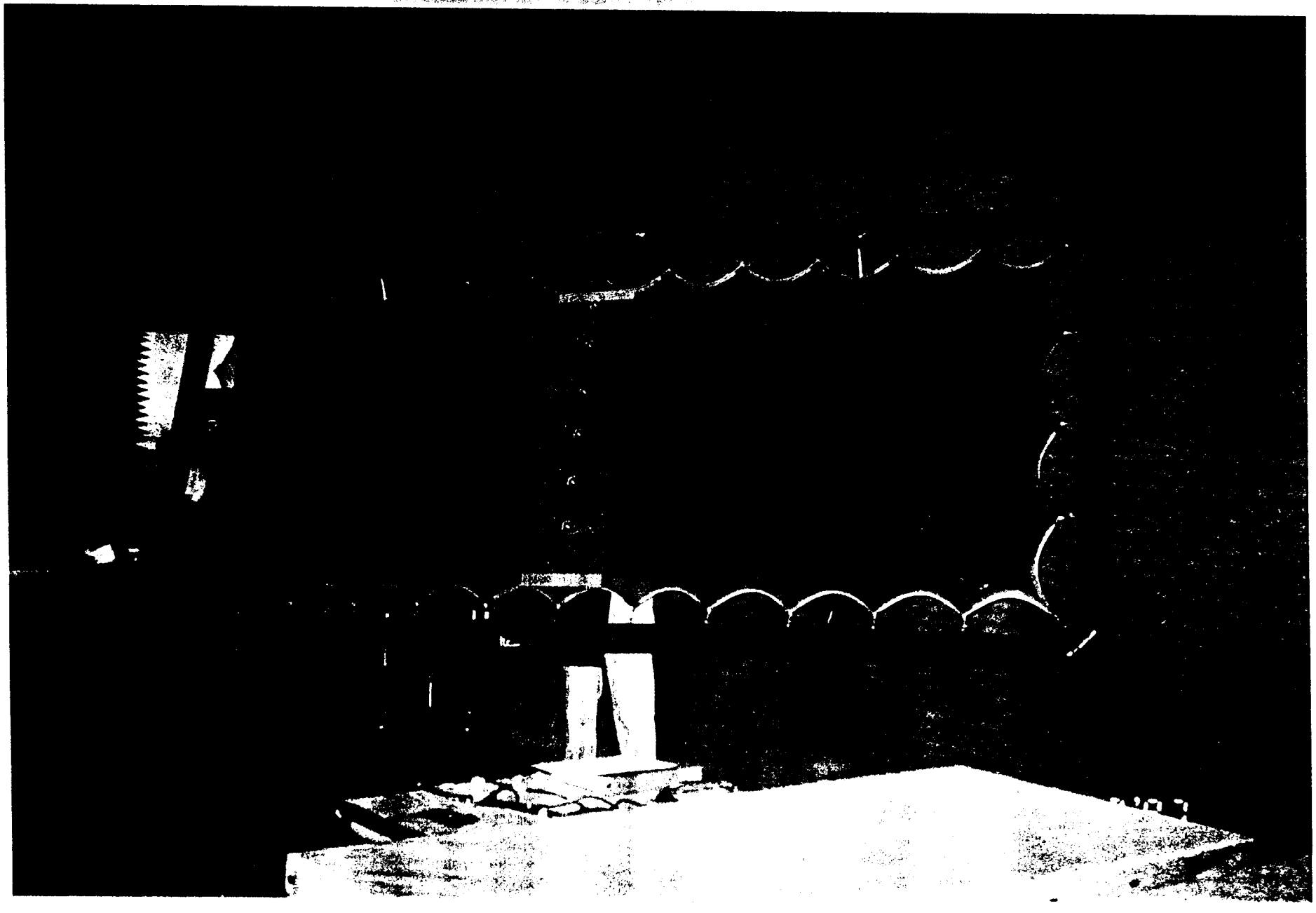
Inflatable Phased Array

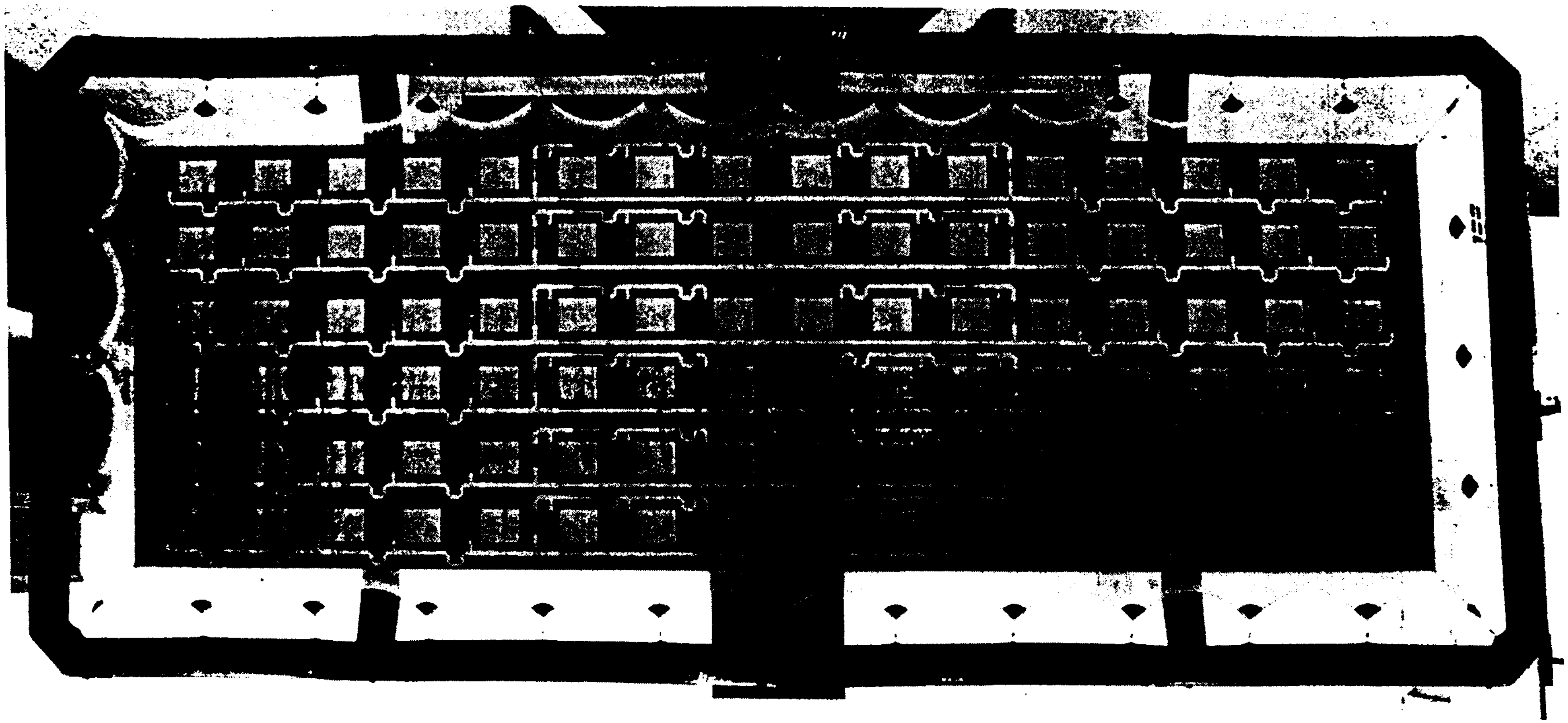
Requirements:

- Frequency: 1.25 GHz
- Bandwidth: 80 MHz
- Polarization: dual linear
- Sidelobe level: -13 dB
- Cross-pol level: -20 dB
- Efficiency: >50%
- Aperture size: 3.3m x 1.0m
- Mass: <3 kg/m^2
- Surface flatness: 1cm global, 0.08 cm local
- Application: remote sensing SAR radar

Inflatable Planar Microstrip Array







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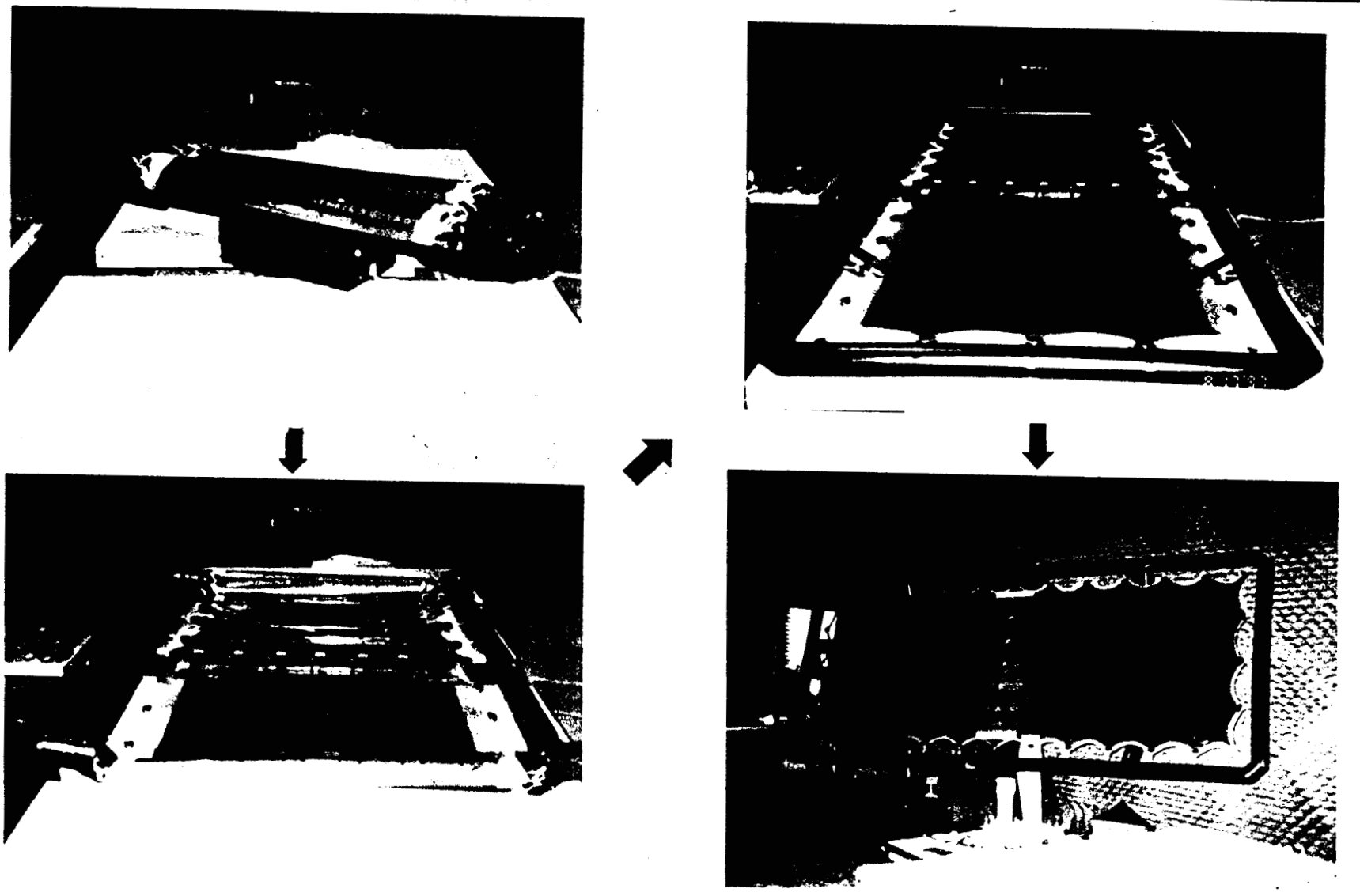
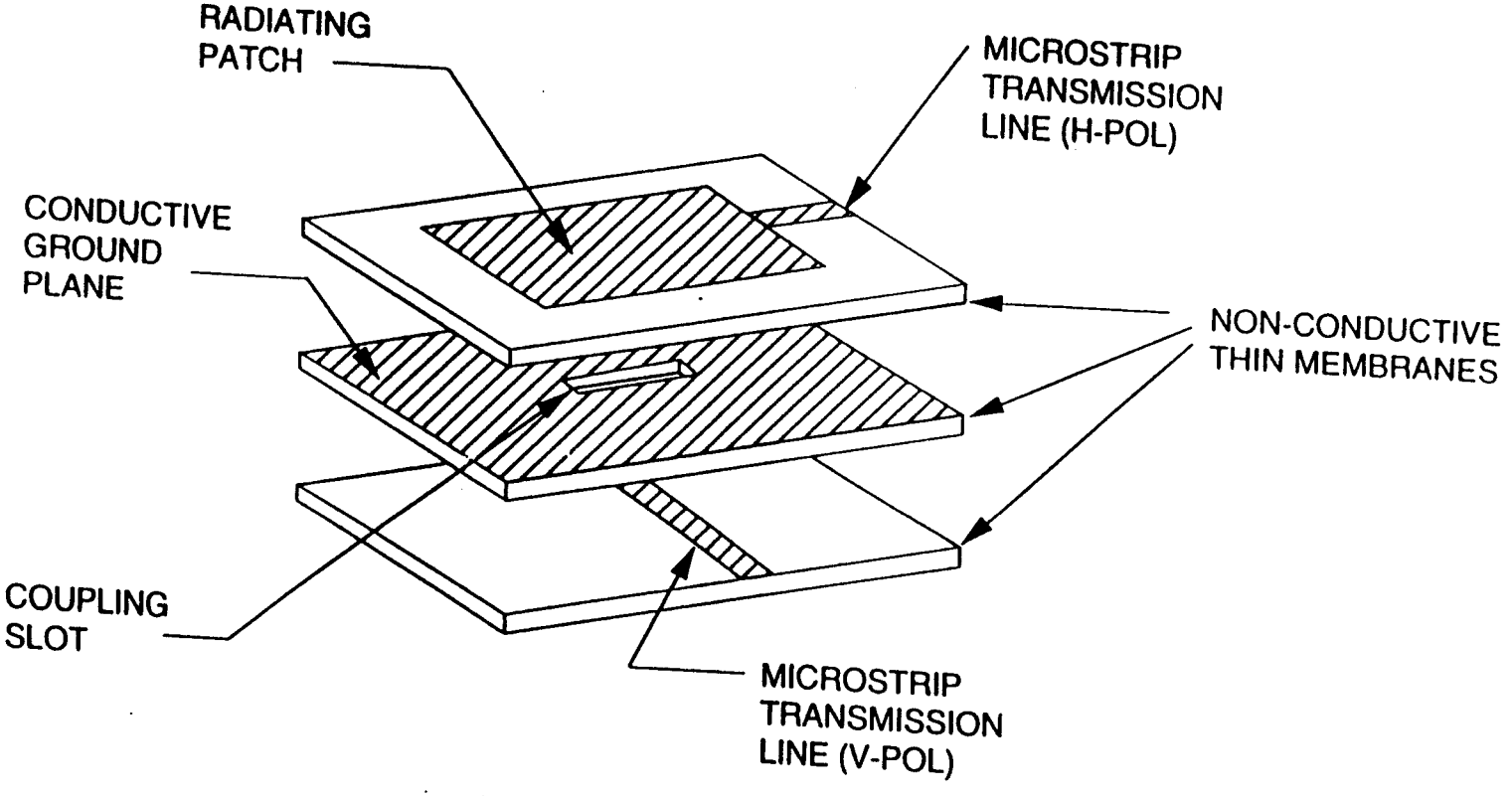
Inflatable SAR Array antenna



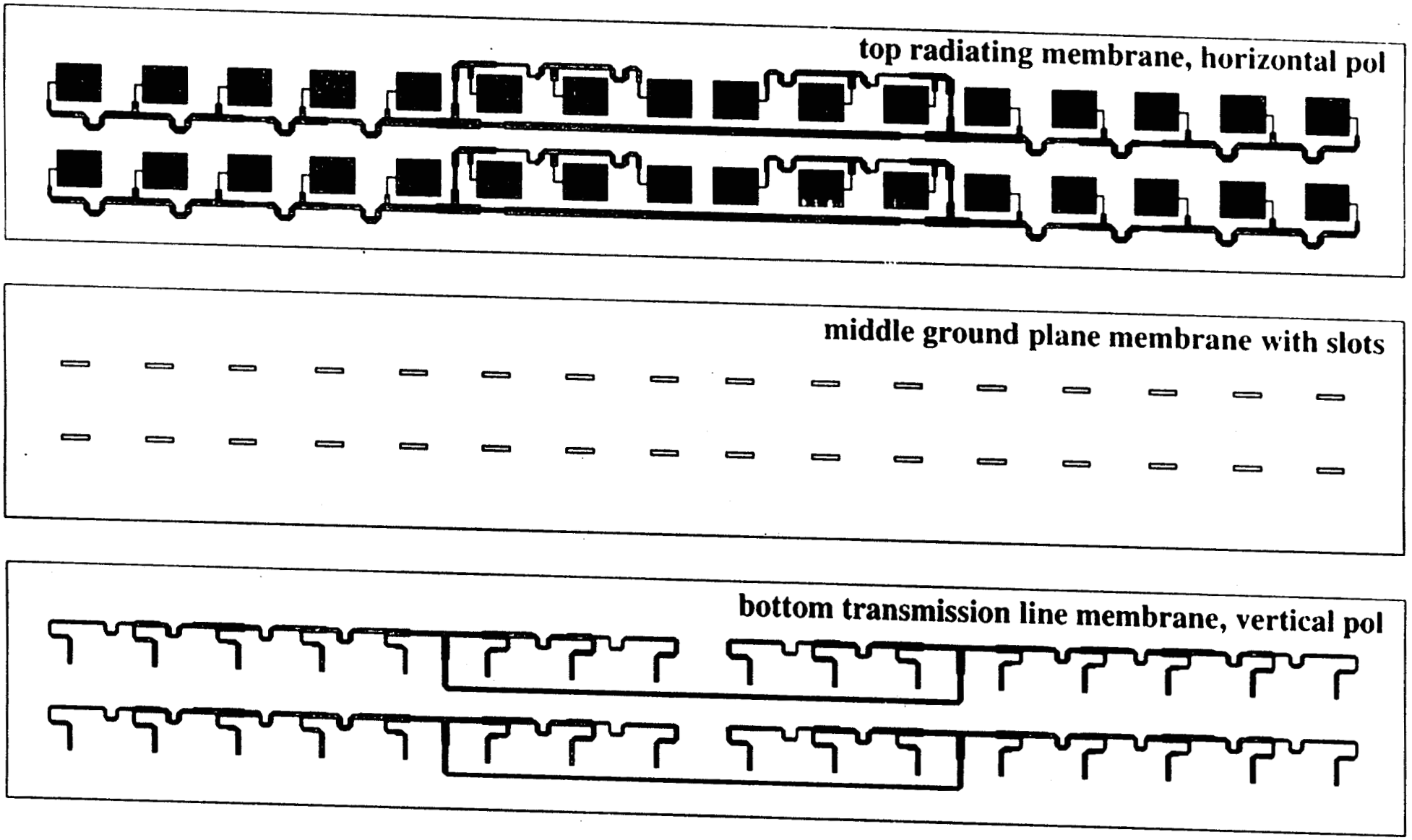
INFLATABLE PLANAR MICROSTRIP ARRAY

Tri-Layer Inflatable Microstrip Antenna Element Section



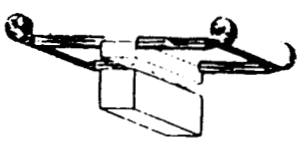
ALL METAL LAYERS ARE EACH 5-MICRON THICK
ALL THIN MEMBRANES ARE EACH 50-MICRON (2-MIL) THICK

Inflatable Microstrip SAR Array
Dual-Pol Aperture Coupled 3 Membrane-Layers



INFLATABLE SAR ARRAY RF DESIGN

- PRINTED MICROSTRIP PATCH ARRAY WITH AIR SUBSTRATE USING THIN MEMBRANES, TOP 2 MEMBRANES SPACING = 0.5", BOTTOM 2 MEMBRANES SPACING = 0.25"
- THIN MEMBRANE HAS 5-MICRON COPPER ON 2-MIL KAPTON® (5-MICRON COPPER => 2 SKIN DEPTH AT L-BAND)
- MICROSTRIP POWER DIVIDER LINES USE PARALLEL/SERIES COMBINATION: PARALLEL TO ACHIEVE BANDWIDTH, SERIES TO MINIMIZE NEEDED REAL ESTATE
- 3 MEMBRANE LAYERS:
  - top layer has radiating patches and horizontal-pol power divider lines
  - middle layer is ground plane with aperture coupling slots
  - bottom layer has vertical-pol power divider lines
- CENTRAL FEED PROBES ALLOW CONNECTION TO T/R MODULES AND PHASE SHIFTERS FOR ELECTRONIC BEAM SCANNING IN ONE DIMENSION



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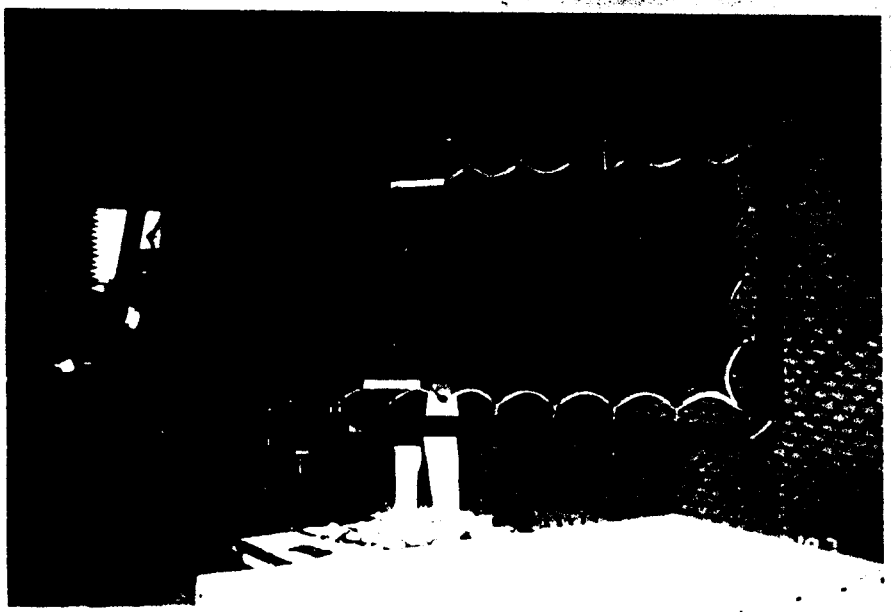
Inflatable SAR Array Antenna

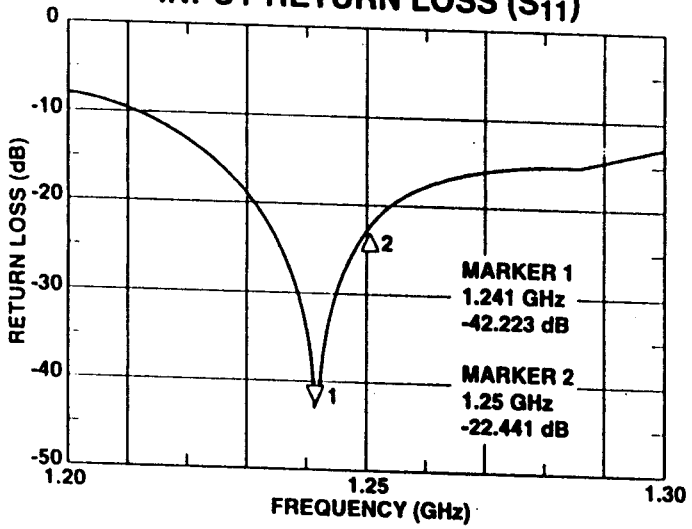


CHARACTERISTICS:

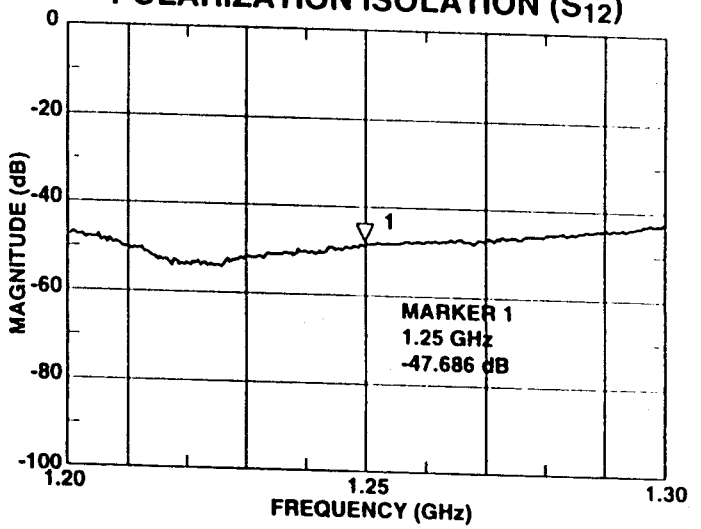
- frequency: L-band (1.25 GHz)
- bandwidth: 80 MHz
- size: 3.3 m x 1 m aperture
- mass: 15.3 Kg
- polarization: dual linear
- peak gain: 25.2 dB
- efficiency: 52%
- surface flatness: $\leq \pm 0.075$ cm
- material: kevlar tube/kapton membrane

INFLATABLE SAR ARRAY ANTENNA
RF TEST RESULTS

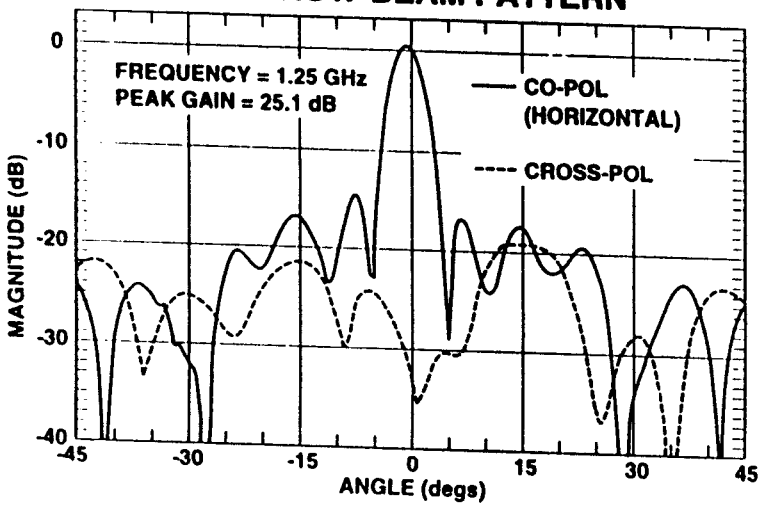
INPUT RETURN LOSS (S_{11})



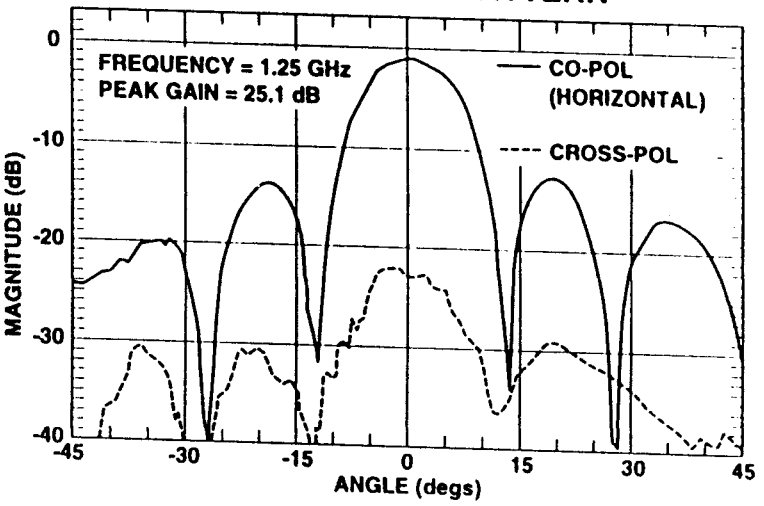
POLARIZATION ISOLATION (S_{12})

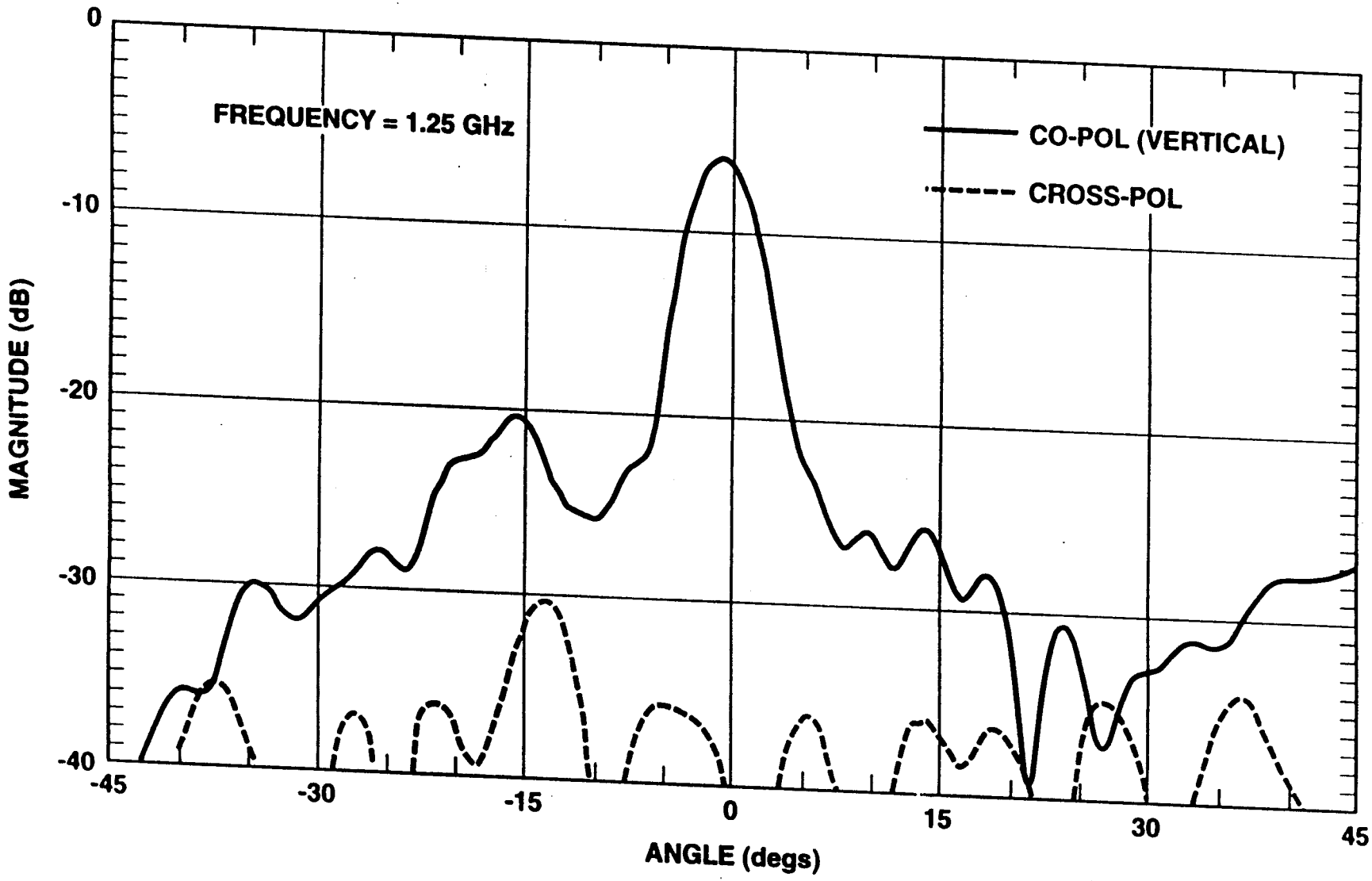


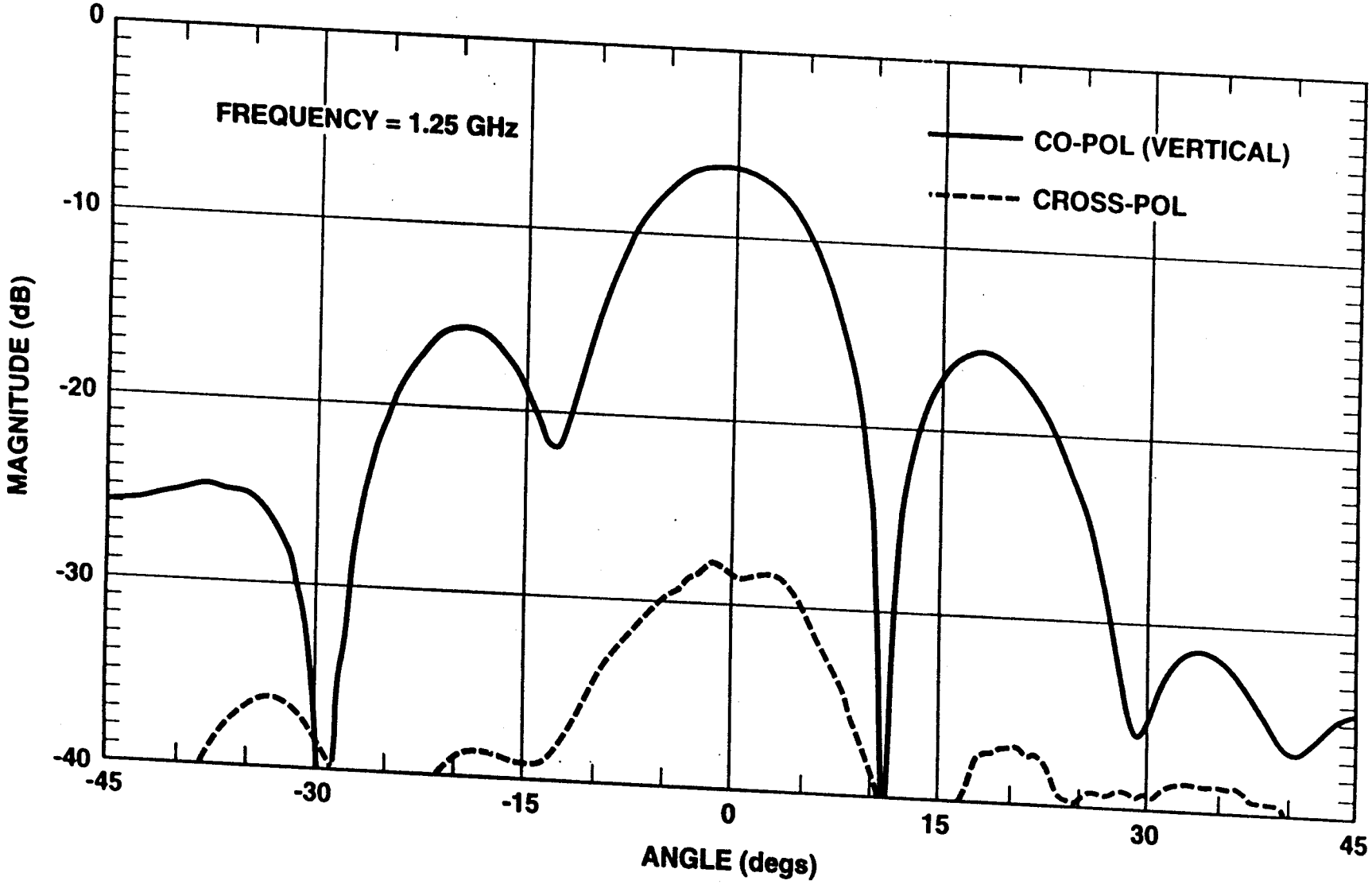
NARROW-BEAM PATTERN



BROAD-BEAM PATTERN




FREQUENCY = 1.25 GHz
CO-POL (VERTICAL)
CROSS-POL
MAGNITUDE (dB)
0
-10
-20
-30
-40
-45
-30
-15
0
15
30
45
ANGLE (degs)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0
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-45
-30
-15
0
15
30
45
ANGLE (degs)

Technical Challenges and Key Issues

- Achieve 80 MHz (6.4%) bandwidth and dual polarization
- Maintain required flatness, proper separation, and accurate alignment of the multi-layer membrane structure
- Need in-space rigidization techniques (stretched aluminum, water-based gel, thermalplastic composite, etc.)
- Need controlled deployment mechanisms
- Need membrane-mountable T/R modules and components
- Reduction of size and mass of inflatation system

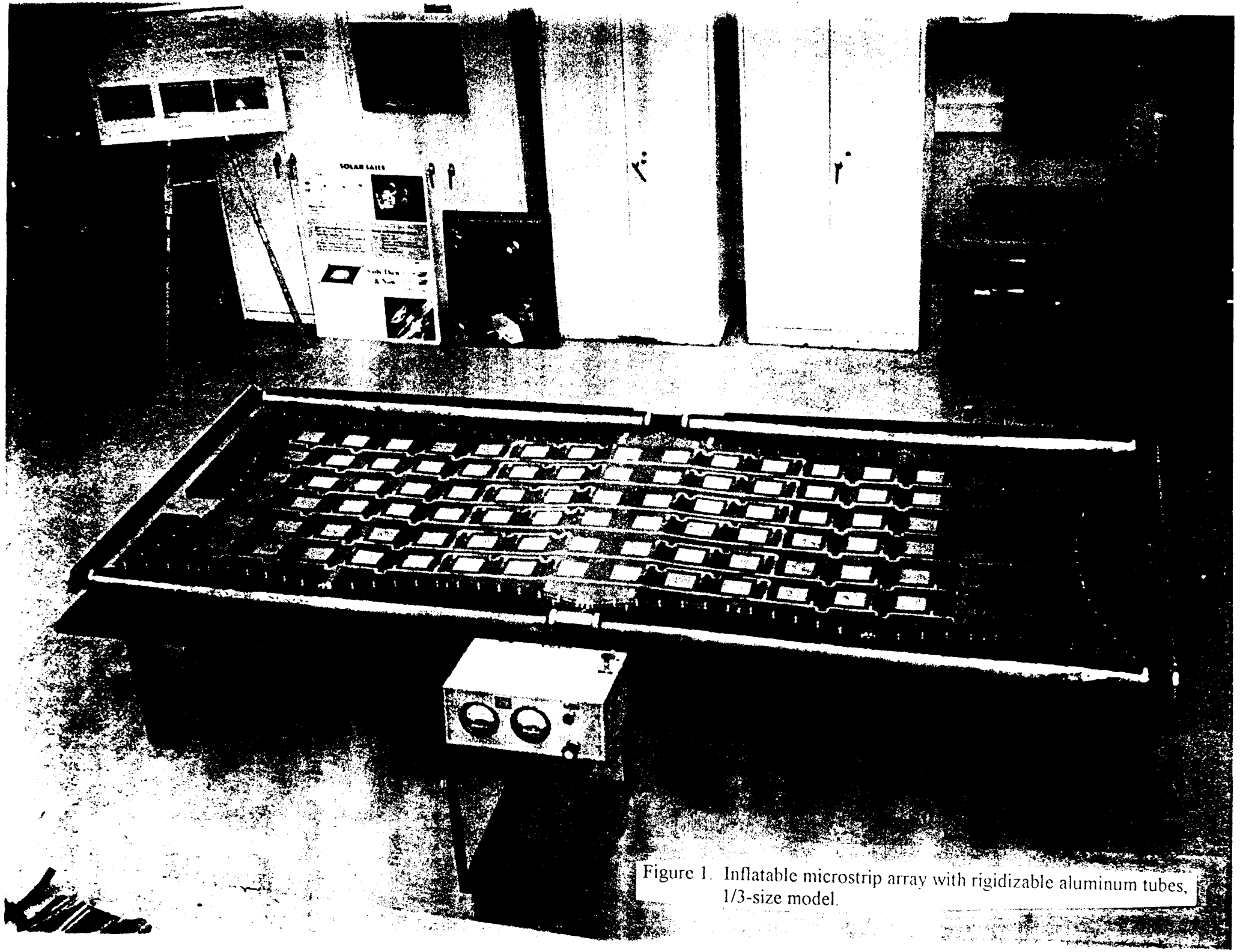
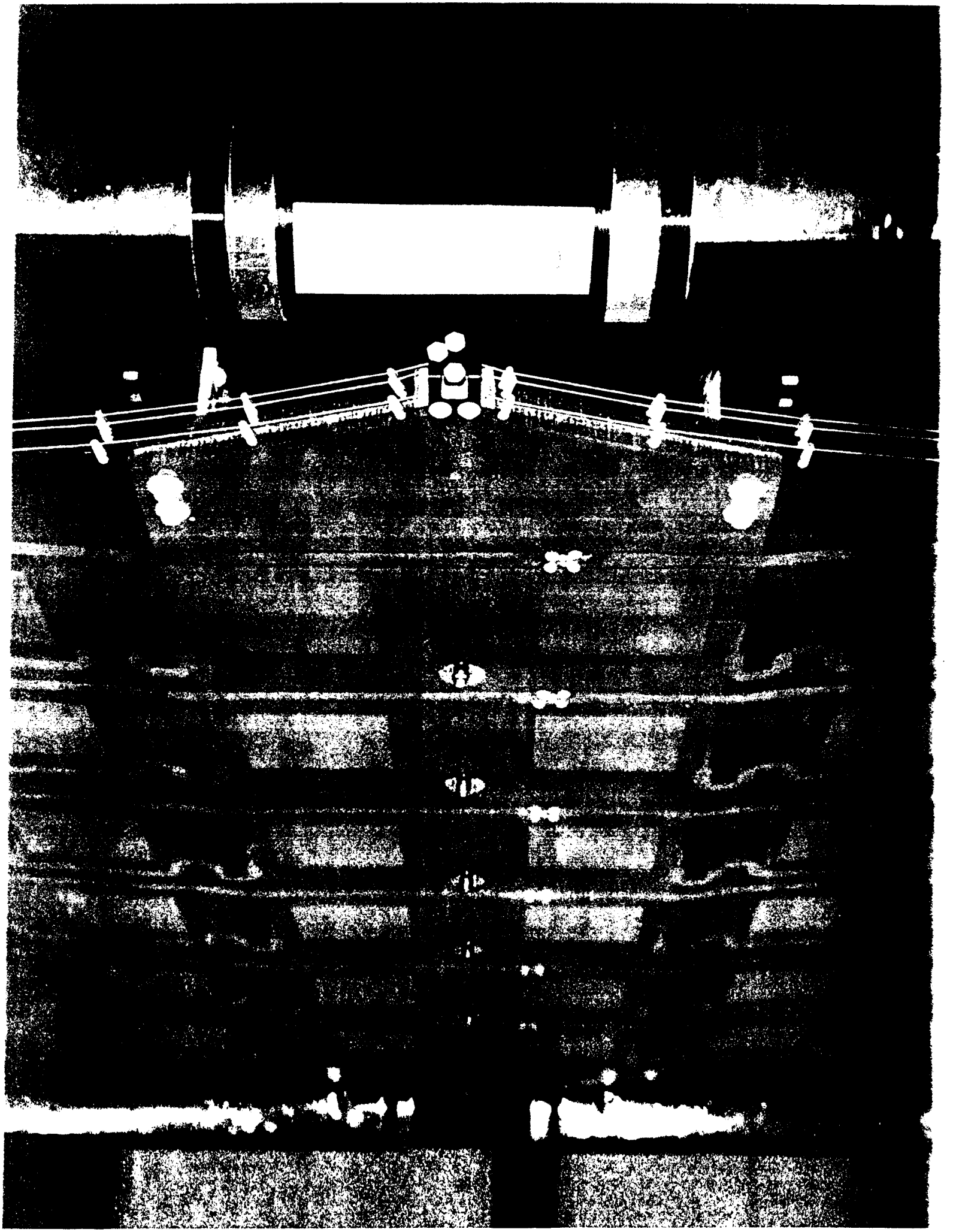
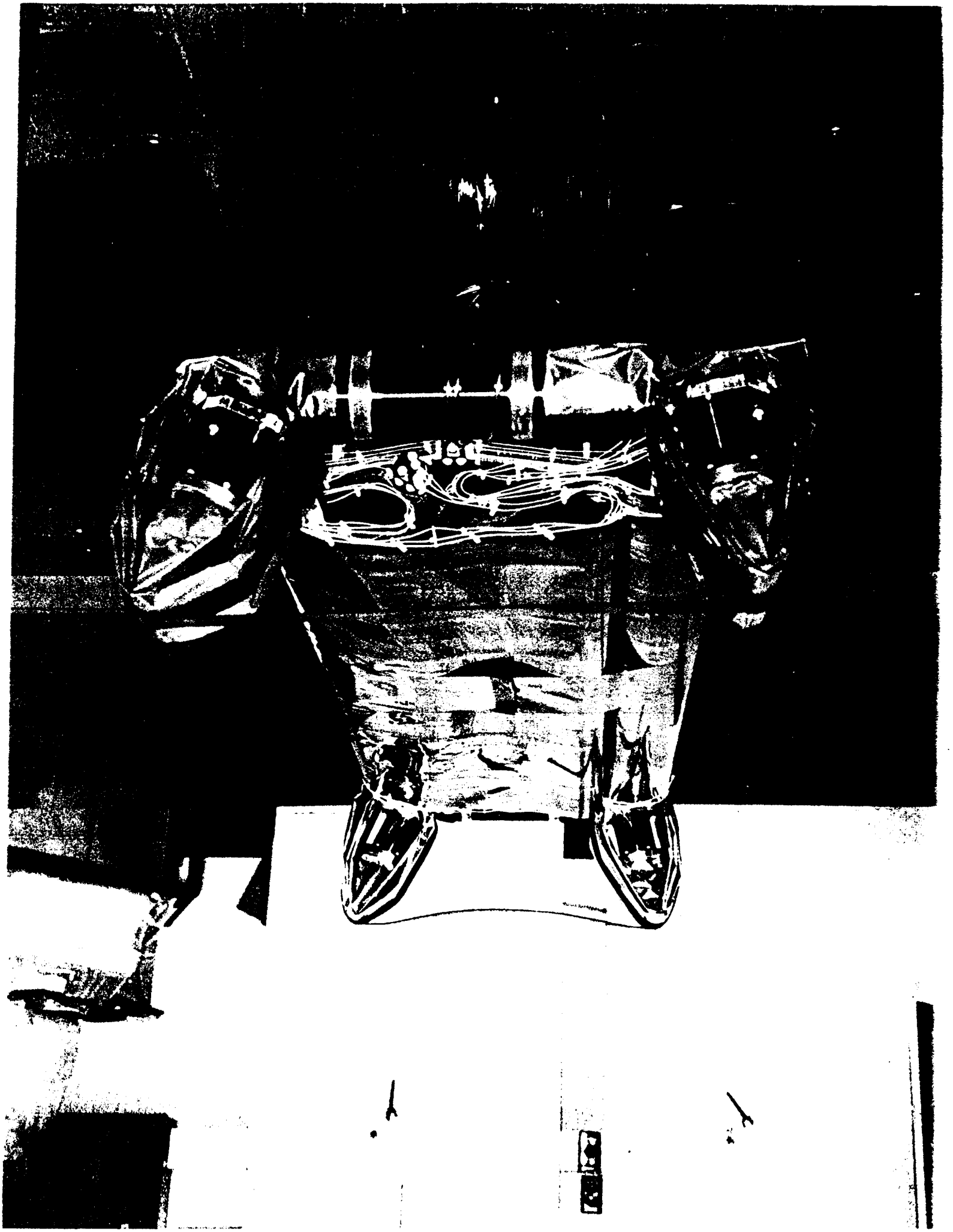
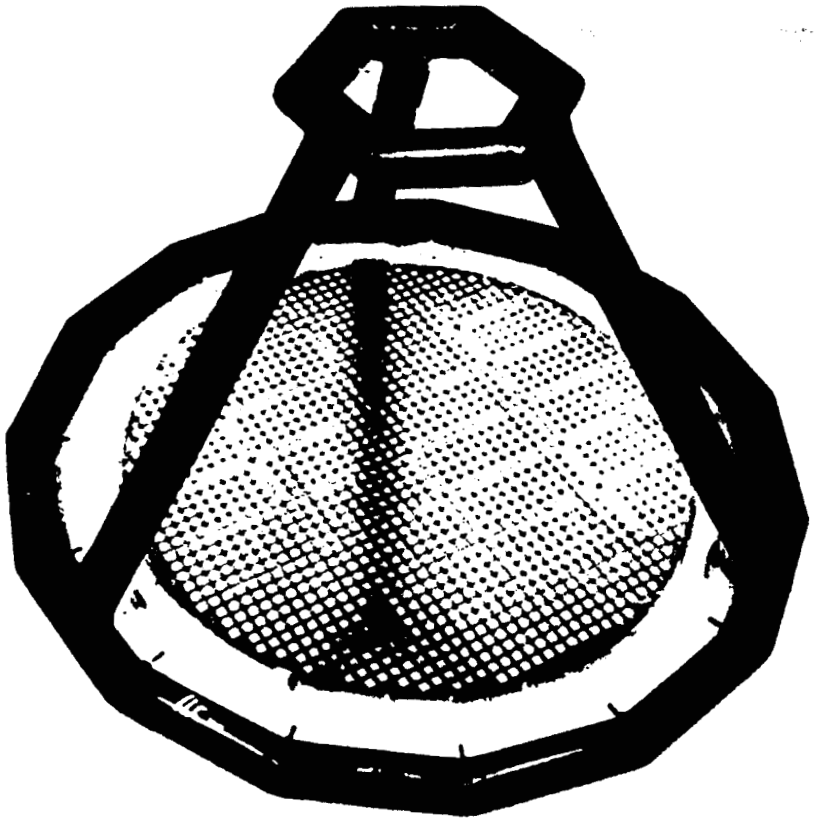


Figure 1. Inflatable microstrip array with rigidizable aluminum tubes, 1/3-size model.





JPL 1 m X-Band Inflatable Microstrip Reflectarray



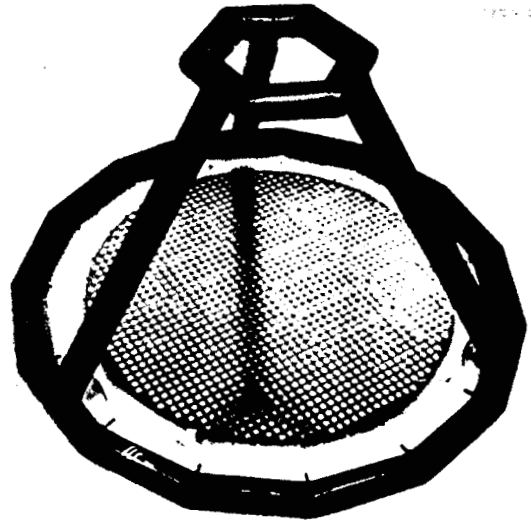
CHARACTERISTICS:

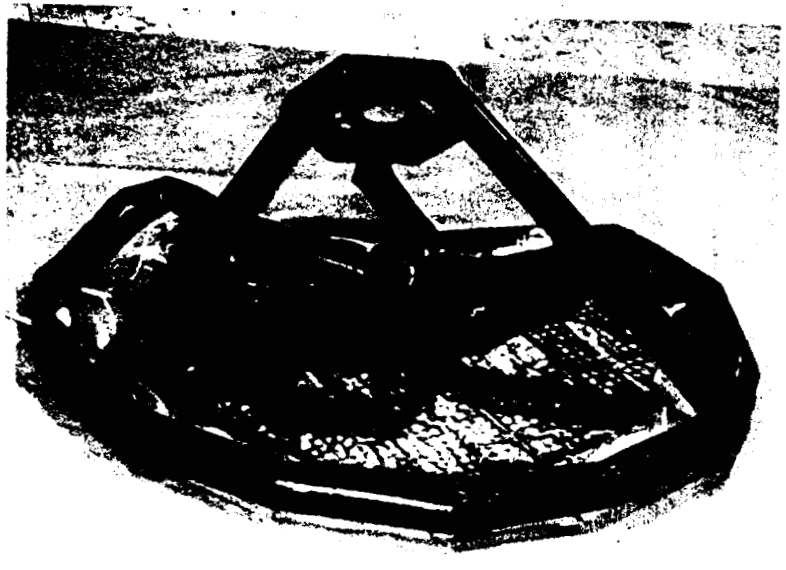
- mass: 1.2 Kg
- 3dB beamwidth: 2.4°
- peak gain: 33.7 dB
- efficiency: 37% (room for improvement)
- polarization: circular
- surface flatness: $\leq \pm 0.075$ cm
- Material: kevlar tube/kapton membrane

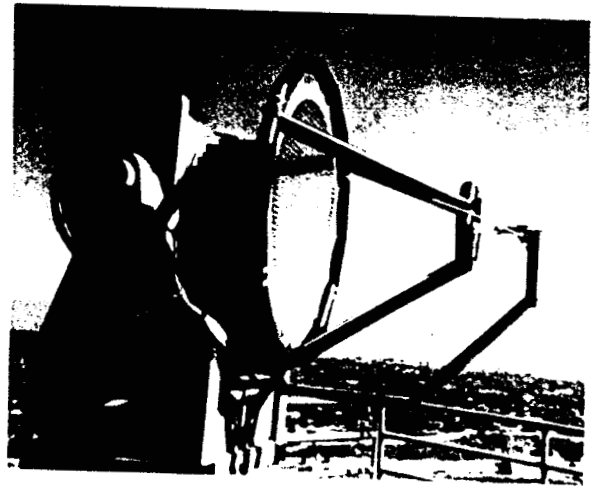
ADVANTAGE:

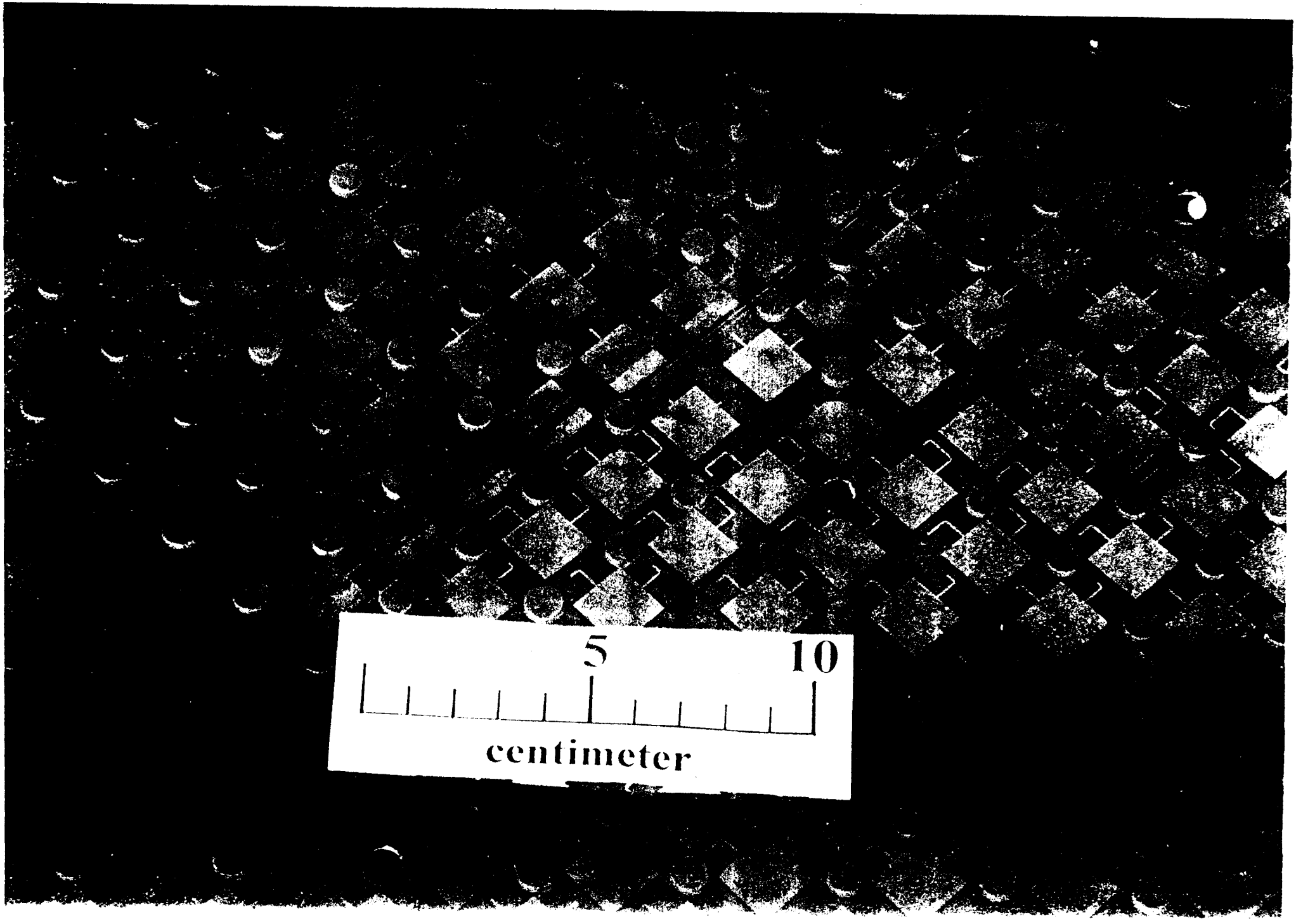
easier and more reliable to maintain surface flatness than inflatable parabola

JPL 1 m X-Band Inflatable Microstrip Reflectarray

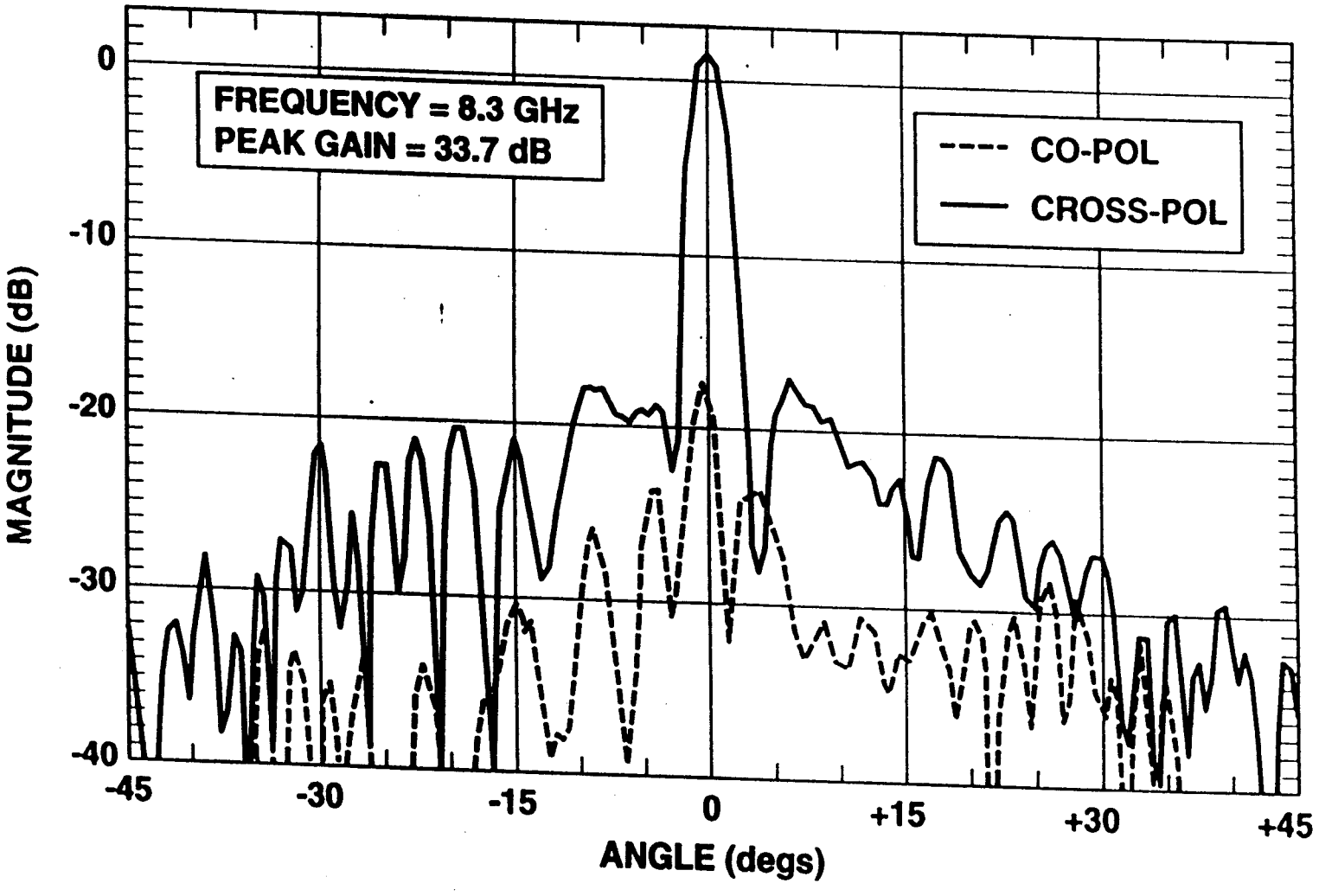






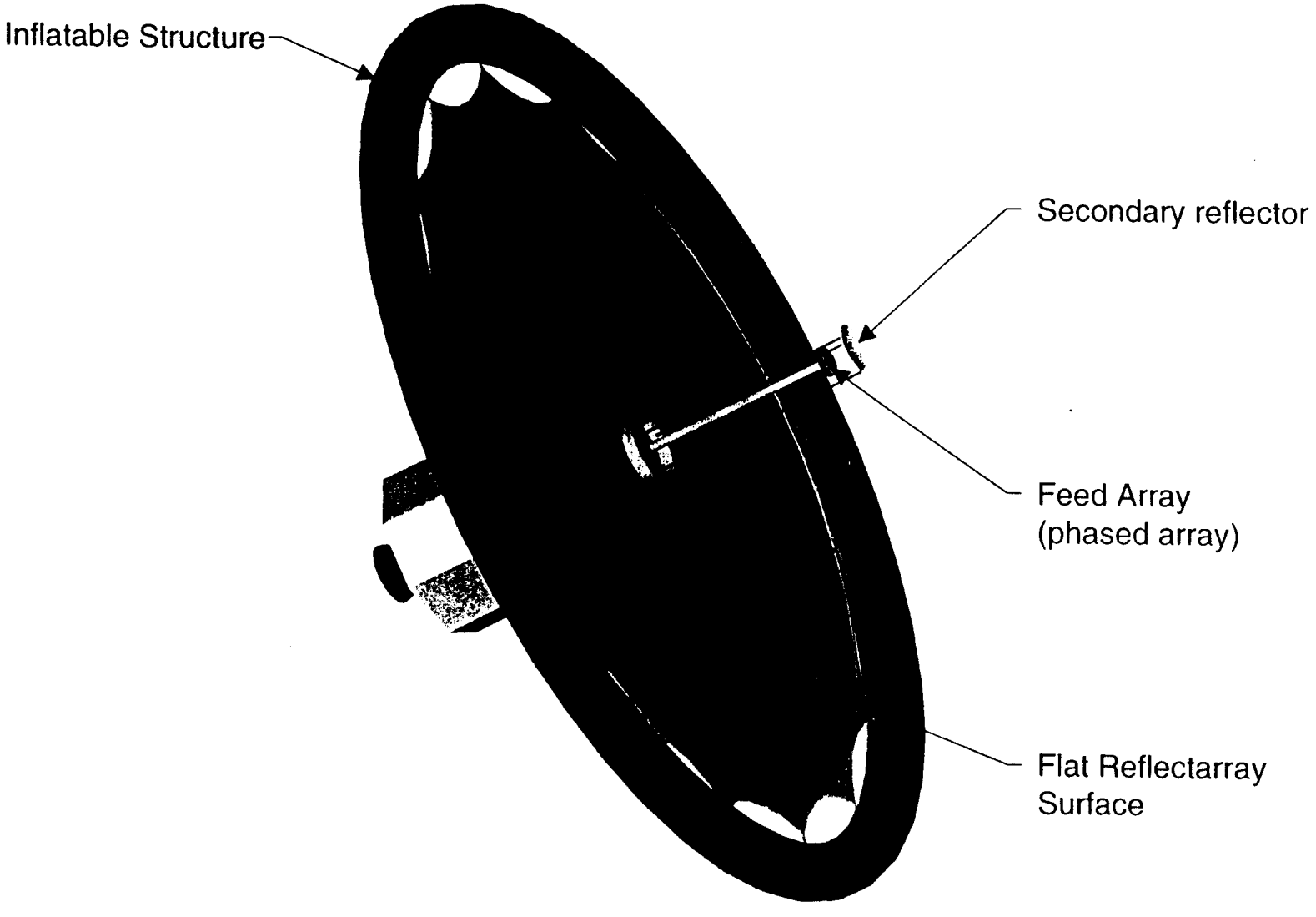

5
10
centimeter

Measured pattern of the 1-meter circularly polarized inflatable microstrip reflectarray antenna



3m Inflatable Ka-band Reflectarray Antenna

Cassegrain Feed



Summary

- Inflatable array antennas are realizable both electrically as well as mechanically in the microwave frequency band up to Ka-band
- Material survivability in space environment may need more development
- Membrane mounted RF components (T/R module, phase shifter, etc.) need to be developed
- Low-mass inflation system need to be developed

3-m Ka-Band Inflatable Reflectarray